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(54) Inductively and multi-capacitively coupled plasma reactor

(57) The invention is embodied in a plasma reactor for processing a semiconductor wafer (61), the reactor having a pair of parallel capacitive electrodes (60,62) at the ceiling (54) and base (56) of the processing chamber (50), respectively, each of the capacitive electrodes (60,62) capacitively coupling RF power into the chamber (50) in accordance with a certain RF phase relationship between the pair of electrodes (60,62) during processing of the semiconductor wafer (61) for ease of plasma ignition and precise control of plasma ion energy and process reproducibility, and an inductive coil (74) wound around a portion of the chamber (50) and inductively coupling RF power into the chamber for independent control of plasma ion density. Preferably, in order to minimize the number of RF sources (72) while providing independent power control, the invention includes power splitting to separately provide power from a common source or sources to the pair of electrodes (60,62) and to the coil (74).

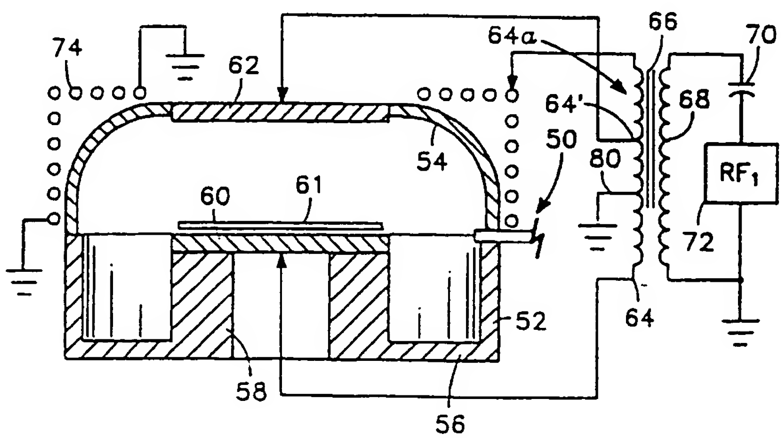

FIG. 4

applied to at least two of the following three elements: the two electrodes and the coil, the capacitive and inductive coupling being carried out during processing of the semiconductor wafer for ease of plasma ignition and precise control of plasma ion energy and process reproducibility. In one embodiment, the certain phase relationship between the two signals may be, for example, 180 degrees out of phase.

Preferably, in order to minimize the number of RF sources while providing independent power control, the invention includes power splitting to separately provide power from a common source or sources to the pair of electrodes and to the coil. Specifically, power is reactively split between at least two of the three elements constituting the coil and the pair of electrodes. The power may be inductively split through either a coil or transformer or may be capacitively split by a set of capacitors having a common electrode connected to a common RF source.

The RF power may be inductively split through a transformer and the pair of electrodes are connected to opposite sides of the secondary winding of the transformer. In this case, the inductive coil may be separately powered. Alternatively, both the inductive coil and the electrodes are connected to certain taps on the secondary winding of the transformer. As yet another alternative, the RF power may be inductively split through the inductive coil itself. For example, the power splitting may be carried out by tapping either one or both of the pair of electrodes to one winding of the inductive coil.

Preferably, the top electrode is sufficiently close to the ceiling and has sufficient RF power applied thereto to sputter contaminant deposits off of the ceiling to keep it clean.

In one embodiment, the chamber ceiling includes a portion consisting of a precursor material for a processing gas which is sputtered into the plasma under the influence of the capacitive electrode at the ceiling. The ceiling may be a multi-radius dome shape while the coil inductor may be conformal or non-conformal with the dome-shaped ceiling.

Preferably, the bottom capacitive electrode is the wafer pedestal while the top capacitive electrode is either inside the chamber or else is outside of the chamber. If the top electrode is inside the chamber, then it may be an integral part of the ceiling.

Further features and advantages of this invention will become more readily apparent from the following detailed description when taken in conjunction with the accompanying drawings, in which:

FIG. 1 is a diagram of a capacitively coupled RF plasma reactor of the prior art.

FIG. 2 is a diagram of an inductively coupled RF plasma reactor of the prior art.

FIG. 3 is a diagram of a first embodiment of the invention employing inductive RF power splitting.

FIG. 4 is a diagram of a second embodiment of the invention.

FIG. 5 is a diagram of one embodiment of an inductive coil employed in carrying out the invention.

FIG. 6 is a diagram of a third embodiment of the invention.

FIG. 7 is a diagram of a fourth embodiment of the invention.

FIG. 8 is a diagram of a fifth embodiment of the invention employing capacitive power splitting.

FIG. 9 is a diagram of a sixth embodiment of the invention.

Referring to FIG. 3, a plasma reactor has a vacuum chamber 50 including a cylindrical side wall 52 and a dome-shaped ceiling 54. A floor 56 supports a pedestal 58 which includes a bottom insulated capacitive electrode 60 supporting a semiconductor wafer 61 to be processed by the reactor. The ceiling 54 includes a top insulated capacitive electrode 62 facing the bottom capacitive electrode 60. The top and bottom capacitive electrodes 62, 60 are balanced on opposite sides of the secondary winding 64 of a transformer 66 whose primary winding 68 is connected through a capacitor 70 to an RF power source 72. The RF power source 72 includes an RF power generator and a conventional impedance match network (not shown), such as the RF generator 20 and RF impedance match network 18 of FIG. 1. The RF power source 72 controls the plasma ion energy and capacitive coupling to the plasma. Inductive coupling is provided by an inductive coil 74 wound around a portion of the dome shaped ceiling 54. The coil 74 is powered through a capacitor 76 by a second RF power source 78, including an RF generator and an RF impedance match network (not shown). The power source 78 is connected through the capacitor 76 to the middle winding of the inductor coil 72, the two ends of the coil 74 being grounded to minimize power loss to either the top electrode 72 or the side wall 52.

Apportionment of RF power between the top and bottom electrodes 62, 60 is determined by the location of a ground tap 80 on the secondary winding 64. For example, if the ground tap 80 is connected to the middle coil of the secondary winding 64, then the top and bottom electrodes receive equal amounts of RF power from the RF source 72. On the other hand, if the ground tap 80 is located closer to the connection to the top electrode 62, then more RF power is applied to the bottom electrode 60.

The embodiment of FIG. 3 may be modified so that the top electrode 62 is outside of the chamber 50 and overlies the ceiling 54 (as discussed later herein with reference to FIG. 7)

The connection of the opposing electrodes 60, 62 to opposite ends of the secondary winding 64 establishes a 180-degree out-of-phase relationship between the RF signals imposed on the opposing electrodes 60, 62, thereby maximizing capacitive coupling of RF power to the plasma. However, other suitable RF phase relationships may be chosen in carrying out the invention.

made without departing from the true spirit and scope of the invention.

Claims

1. A capacitively and inductively coupled RF plasma reactor for processing a semiconductor wafer (61) inside a vacuum chamber (50) of said reactor, comprising:

   a pair of parallel capacitive electrodes (60,62) facing each other across at least a portion of the chamber (50);

   an inductive coil (74) wound around a portion of the chamber; and

   at least one RF source (72);

   means for reactively splitting RF power among at least two of: (a) a first one of said capacitive electrodes (60), (b) a second one of said capacitive electrodes (62) and (c) said inductive coil (74).

2. The reactor of claim 1 wherein said means for reactively splitting RF power comprising:

   means for connecting said RF source to said inductive coil; and

   a conductive tap on said inductive coil (74), said conductive tap connected to one of said capacitive electrodes (60,62).

3. The reactor of claim 1 or 2 wherein the other of said capacitive electrodes (60,62) is grounded.

4. The reactor of claim 1 wherein said means for reactively splitting RF power comprise a transformer (66) comprising:

   a primary winding (68), connected to said RF source (72); and

   a secondary winding (64) having a pair of connections, the pair of electrodes (60,62) being connected to respective ones of said connections of the secondary winding (64).

5. The reactor of claim 4 further comprising a second RF source (78) connected to said inductive coil (74).

6. The reactor of claim 4 or 5, wherein said respective connections of said secondary winding (64) are two ends of said secondary winding (64).

7. The reactor of claim 1 or 2, wherein:

   said means for reactively splitting RF power comprise a first connection between one winding (84) of said inductive coil (74) and RF source (72); and

   a connection between another winding (86) of said inductive coil (74), and at least one of said capacitive electrodes (60,62).

8. The reactor of claim 1 wherein said means for reactively splitting RF power comprises a power splitting capacitor comprising:

   a common capacitor electrode (92), connected to the RF source;
   at least first and second parallel capacitor electrodes (94,96,98) facing said common capacitor electrode (92), said first and second parallel capacitor electrodes (94,96,98) being connected to respective ones of said two of said (a) a first one of said capacitive electrodes (62), (b) a second one of said capacitive electrodes (60,62), and (c) said inductive coil (74).

9. The reactor of claim 8 further comprising a phase reversing capacitor (99) connected in series between one of said parallel capacitor electrodes (98) of said power splitting capacitor (90) and one of said capacitive electrodes (60,62) of said chamber (50).

10. The reactor of any of the preceding claims, wherein the chamber (50) comprises a ceiling (54), and one of said capacitive electrodes (62) is a top electrode adjacent said ceiling (54), said ceiling (54) comprising a precursor material for a processing gas which is sputtered into the plasma under the influence of said top electrode (62).

11. The reactor of claim 10 wherein said ceiling (54) comprises a multi-radius dome shape while the inductive coil (74) is one of: (a) conformal with said dome shape and (b) non-conformal with said dome shape.

12. The reactor of claim 10 or 11 wherein the other capacitive electrode (60,62) comprises a wafer pedestal (58) facing said ceiling (54).

13. The reactor of any of claims 10 to 12 wherein said top capacitive electrode (62) is one of: (a) inside the chamber (50), and (b) outside of said chamber (50).

14. The reactor of claim 13 wherein said top electrode (62) is an integral part of the ceiling (54).

15. The reactor of one of claims 10 to 14 wherein said top electrode comprises a conductive layer lying on

capacitor electrodes (94,96,98) being connected to respective ones of said two of said (a) a first one of said capacitive electrodes (60,62) (b) a second one of said capacitive electrodes (60,62), and (c) said inductive coil (74).

28. The reactor of claim 27 further comprising a phase reversing capacitor (99) connected in series between one of said parallel capacitor electrodes (94,96,98) of said power splitting capacitor (90) and one of said capacitive electrodes (60,62) of said chamber (54).

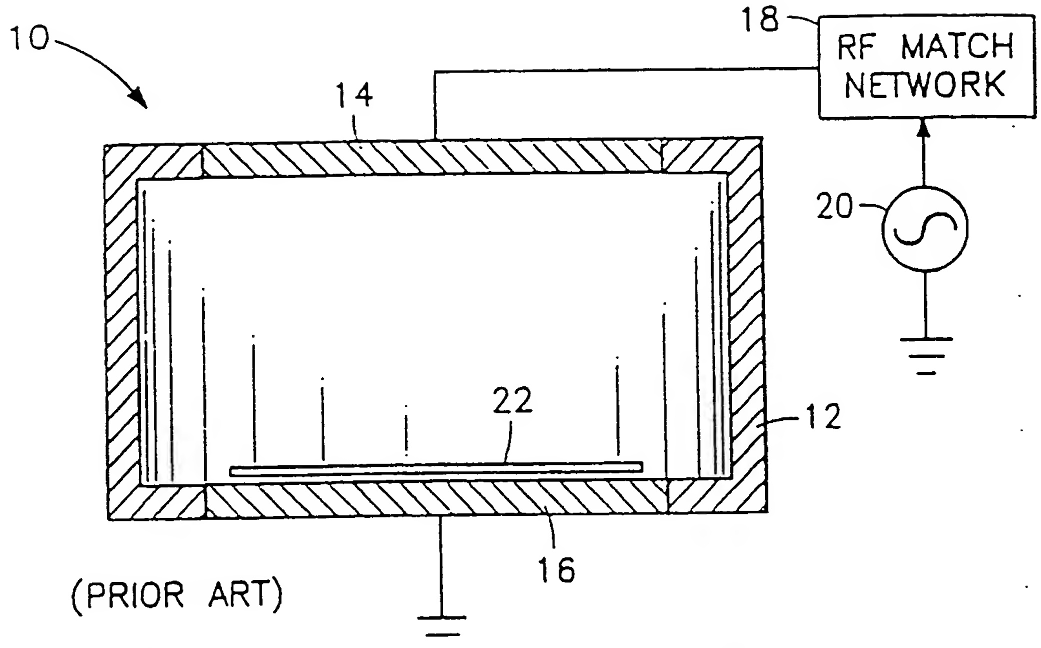
10
14
18
RF MATCH NETWORK
20
22
12
16
(PRIOR ART)

FIG. 1

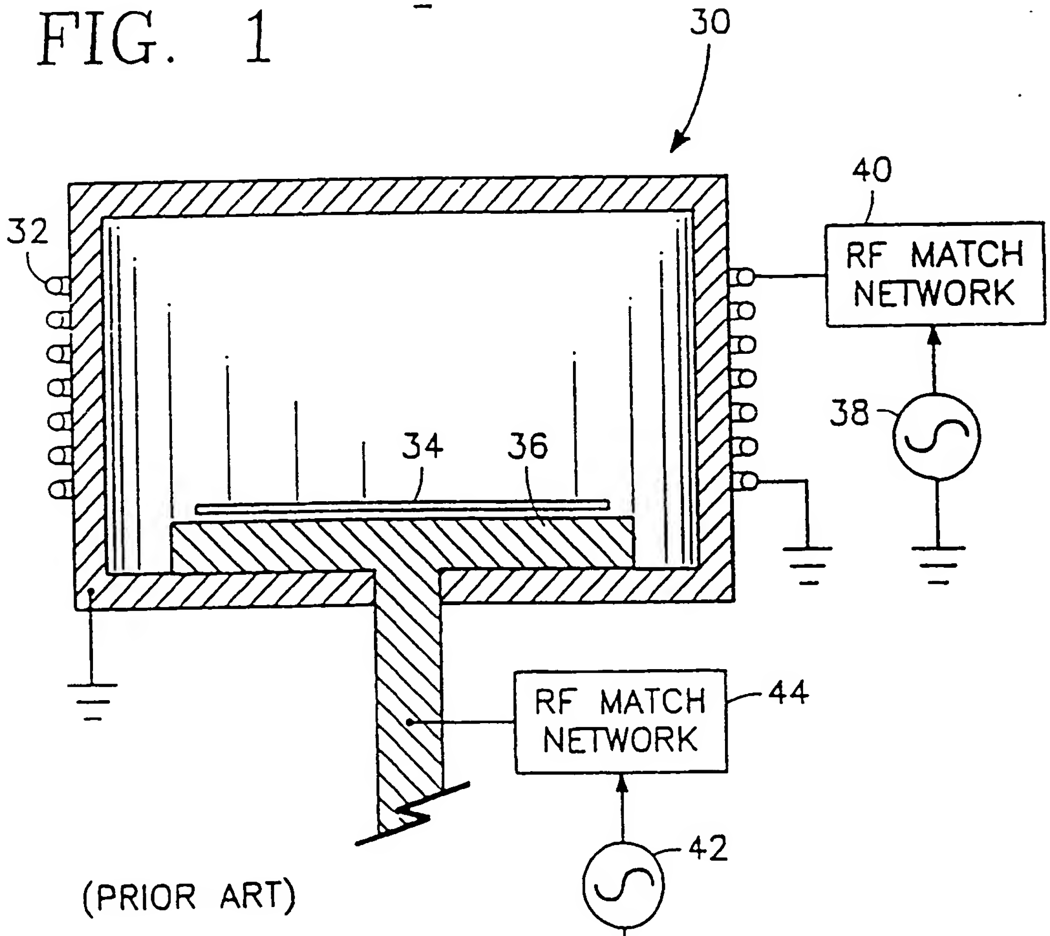
30
32
40
RF MATCH NETWORK
38
34
36
RF MATCH NETWORK
44
42
(PRIOR ART)

FIG. 2

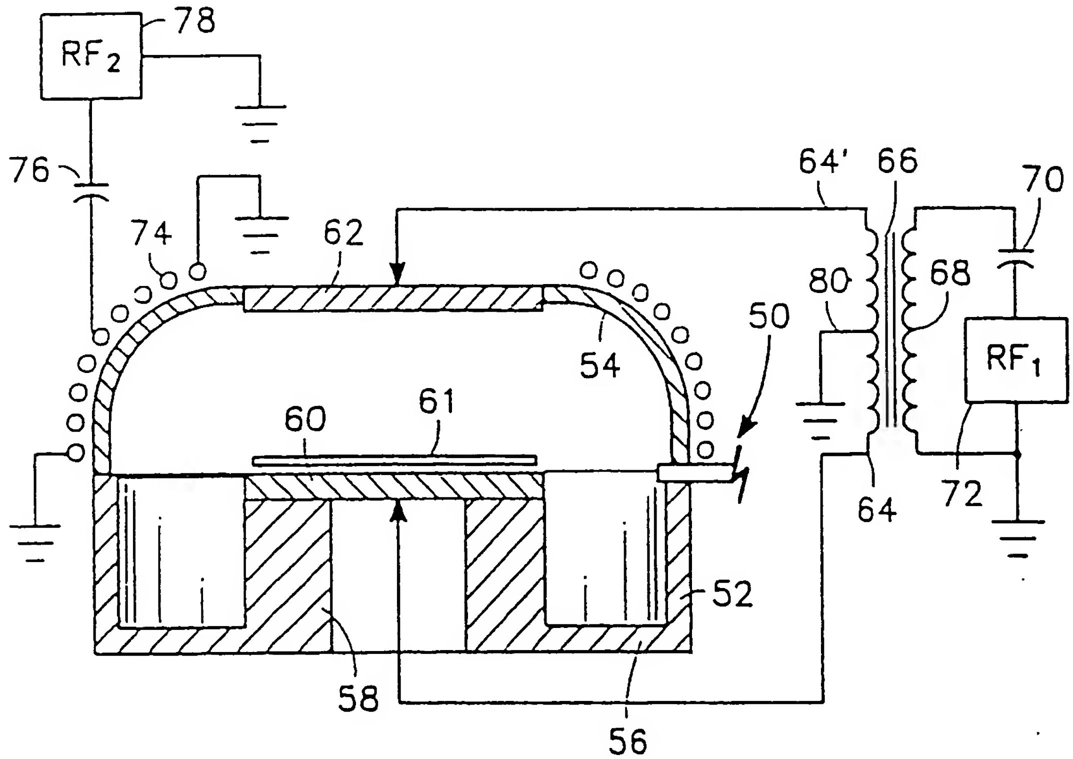
RF2
78
76
74
62
64'
66
70
80
68
50
54
RF1
60
61
72
64
52
58
56

FIG. 3

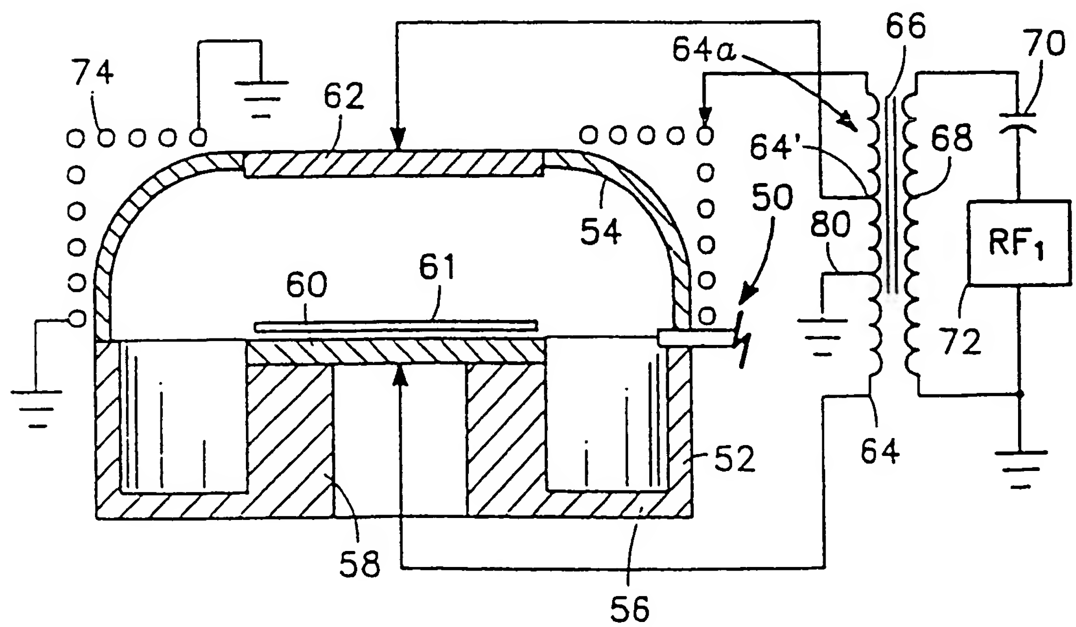
66
64a
70
74
62
68
64'
50
80
54
RF1
60
61
72
64
52
58
56

FIG. 4

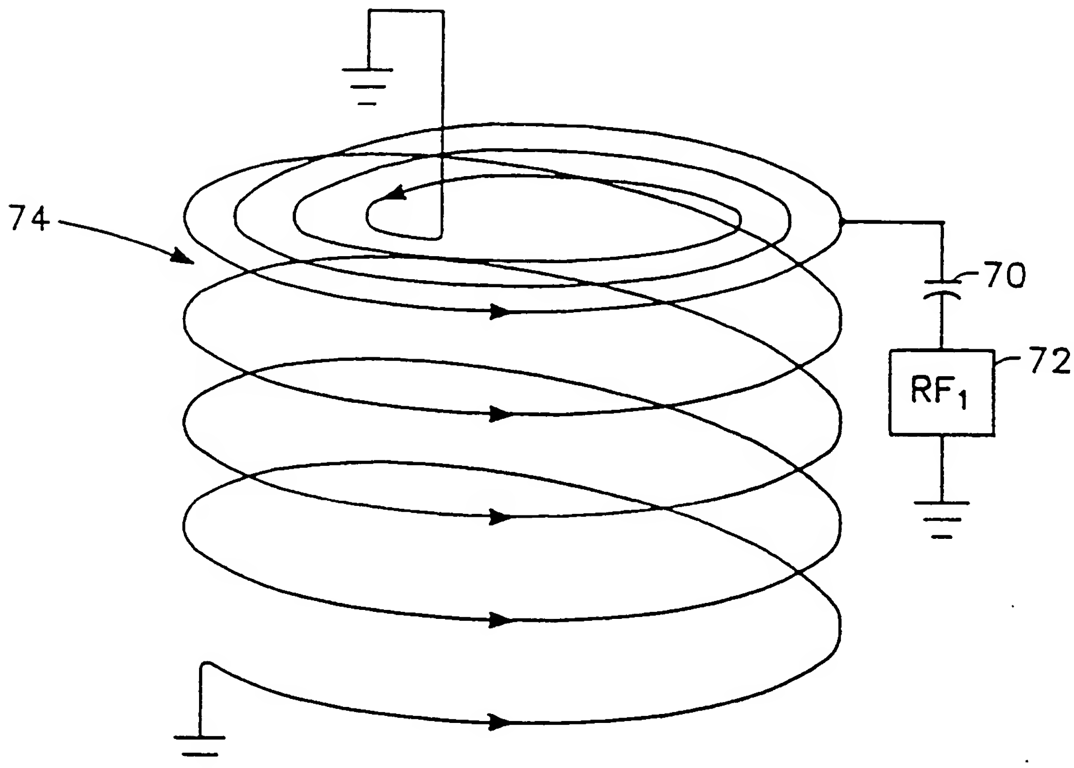

FIG. 5

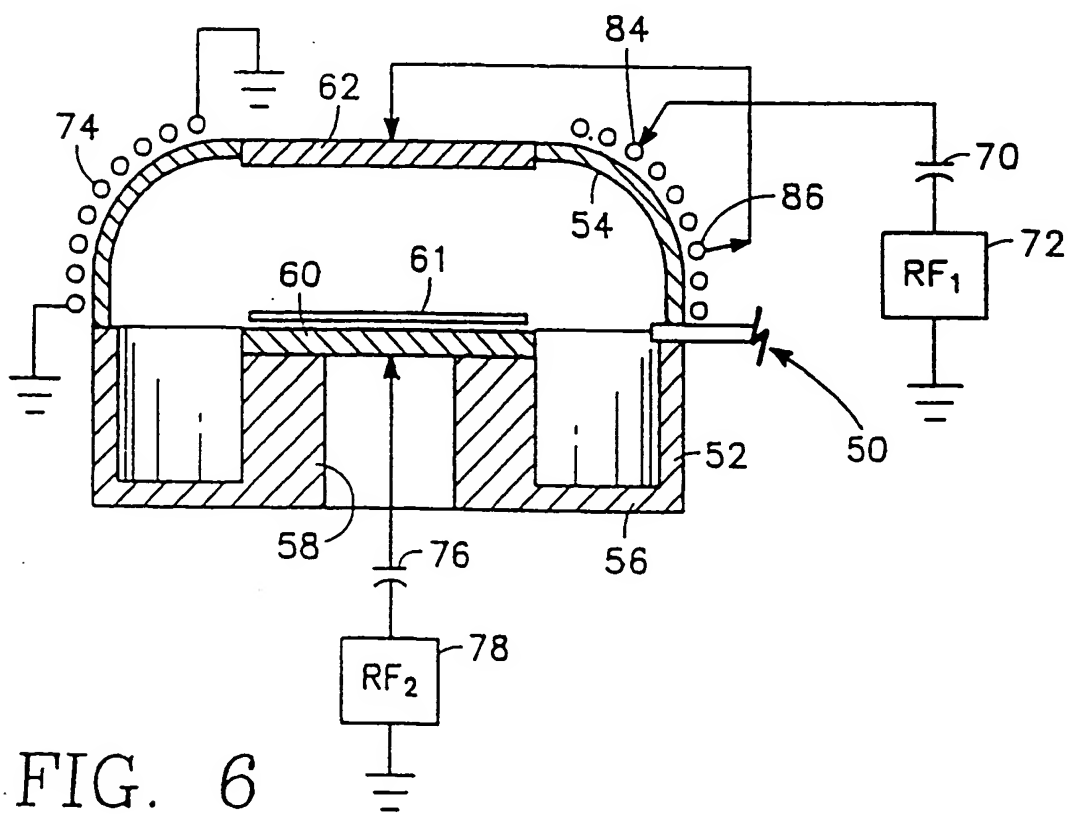

FIG. 6

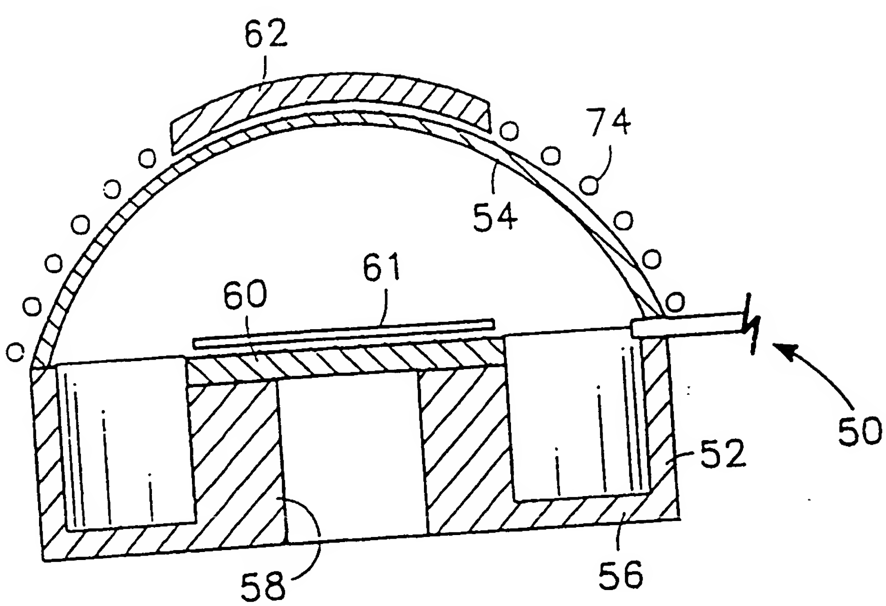

FIG. 7

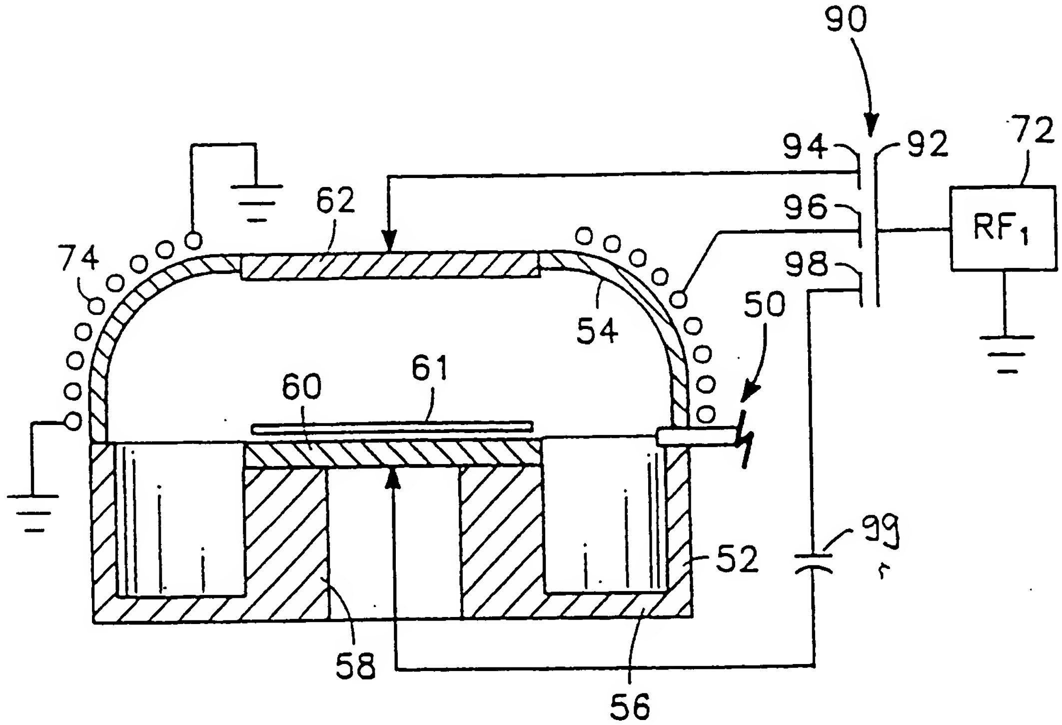
90
94
92
72
96
RF1
98
62
74
54
50
60
61
99
52
58
56

FIG. 8

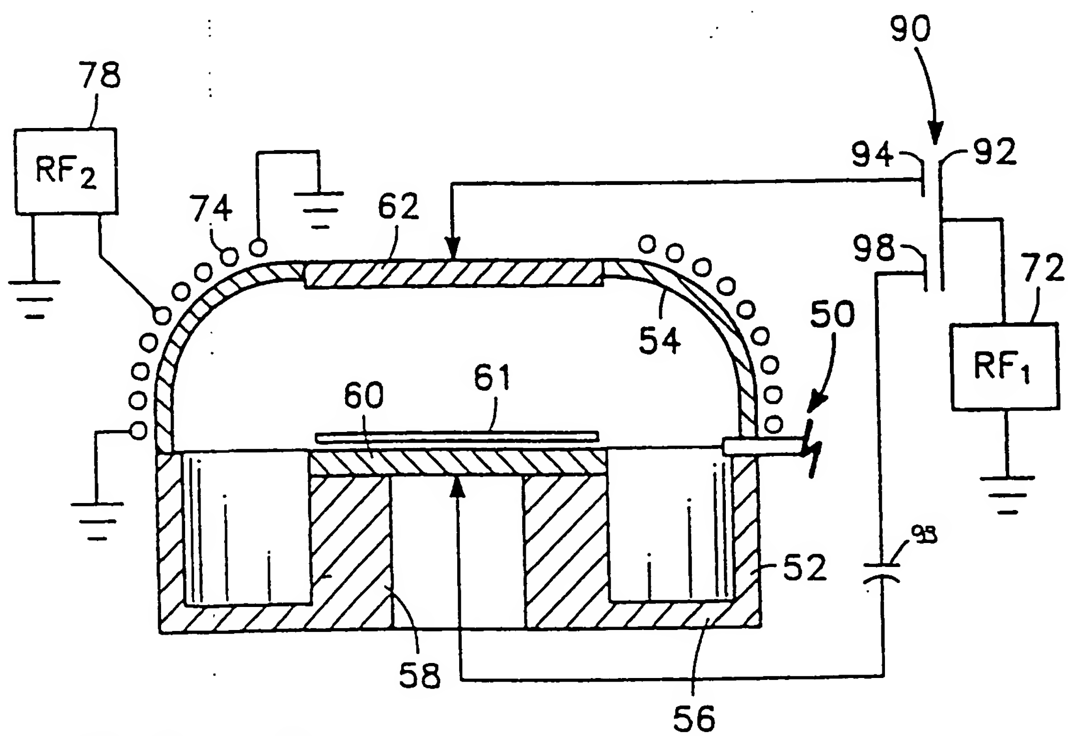
90
78
94
92
RF2
74
62
98
72
50
54
RF1
60
61
99
52
58
56

FIG. 9